Postprint: Reducing the Impact of Indoor Air Particulate Matter on Cardiovascular and Respiratory Physiological Parameters in Older Adults

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Abstract

Background Exposure to indoor particulate matter pollution increases the incidence and mortality of respiratory and cardiovascular diseases, particularly among the elderly population.

Objective To investigate the effects of indoor particulate matter on cardiopulmonary physiological indicators in the elderly and whether short-term use of air purifiers improves cardiopulmonary health in this population.

Methods In January 2020, a randomized, double-blind crossover trial was conducted among 24 healthy elderly residents of a senior apartment in Jiangbei District, Chongqing, China. Participants were randomly divided into two groups and alternately exposed to real and sham air purifiers for 48 hours each, separated by a 12-day washout period. Following each intervention, 14 biomarkers of inflammation, coagulation, and oxidative stress in the circulatory system were measured, along with health indicators including lung function, blood pressure, heart rate, and fractional exhaled nitric oxide (FeNO). Linear mixed-effects models were used to evaluate the impact of air purifiers on these health indicators.

Results Linear mixed-effects model analysis revealed that compared with sham purifiers, use of real purifiers was associated with changes of -15.1% [95%CI (-23.1%, -6.3%), P<0.05] in fibrinogen, -17.7% [95%CI (-22.9%, -12.3%), P<0.05] in monocyte chemoattractant protein-1 (MCP-1), and -17.2% [95%CI (-23.9%, -9.8%), P<0.05] in myeloperoxidase (MPO); changes of -14.9% [95%CI (-21.1%, -8.2%), P<0.05] in plasminogen activator inhibitor-1 (PAI-1) and -13.5% [95%CI (-18.7%, -8.0%), P<0.05] in tissue-type plasminogen activator (t-PA); and a change of -5.8% [95%CI (-10.6%, -0.8%), P<0.05] in heart rate. Each 1 g/m3 increase in indoor fine particulate matter (PM2.5) concentration was associated with increases of 0.51%, 0.48%, 0.56%, 0.49%, 0.43%, 0.31%,

and 0.20% in fibrinogen, MCP-1, MPO, PAI-1, t-PA, D-dimer, and heart rate, respectively (P<0.05).

Conclusion Indoor air purifiers are associated with reduced concentrations of inflammatory and coagulation biomarkers. Air purification may represent a public health measure to improve circulatory and cardiopulmonary health in the elderly.

Full Text

Effects of Reducing Indoor Air Particles on Cardiovascular and Respiratory Physiological Indexes in the Elderly

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Abstract

Background: Exposure to indoor air particle pollution increases the incidence and mortality of respiratory and cardiovascular diseases, particularly among the elderly population. **Objective:** To explore the effect of indoor air particles on cardiopulmonary-related physiological indexes in the elderly and whether short-term use of air purifiers improves cardiopulmonary health in this population. **Methods:** In January 2020, a randomized, double-blind, crossover trial was conducted on 24 healthy older adults selected from a senior apartment in Jiangbei District, Chongqing, China. Participants were randomly divided into two groups that alternately used real and sham air purifiers for 48 hours, with a 12-day washout period between interventions. Following each purification period, 14 biomarkers of circulatory system inflammation, coagulation, and oxidative stress were measured, along with health indicators including lung function, blood pressure, heart rate, and fractional exhaled nitric oxide (FeNO). Linear mixed-effects models were applied to evaluate the impact of air purifiers on health indicators. **Results:** Linear mixed-effects model results showed that compared with sham purifiers, use of real purifiers was associated with changes of -15.1% [95%CI (-23.1%, -6.3%), P<0.05], -17.7% [95%CI (-22.9%, -12.3%), P<0.05], and -17.2% [95%CI (-23.9%, -9.8%), P<0%] in blood inflammatory markers fibrinogen, monocyte chemoattractant protein-1 (MCP-1), and

myeloperoxidase (MPO), respectively. Coagulation factors plasminogen activator inhibitor-1 (PAI-1) and tissue-type plasminogen activator (t-PA) changed by -14.9% [95%CI (-21.1%, -8.2%), P<0.05] and -13.5% [95%CI (-18.7%, -8.0%), P<0.05], respectively. Heart rate changed by -5.8% [95%CI (-10.6%, -0.8%), P<0.05]. For every 1 g/m^3 increase in indoor fine particulate matter (PM2.5) concentration, fibrinogen, MCP-1, MPO, PAI-1, t-PA, D-dimer, and heart rate increased by 0.51%, 0.48%, 0.56%, 0.49%, 0.43%, 0.31%, and 0.20%, respectively (P<0.05). **Conclusion:** Indoor air purifiers are associated with reduced concentrations of inflammatory and coagulation biomarkers. Air purification may serve as a public health measure to improve circulatory and cardiopulmonary health in the elderly.

Keywords: Particulate matter; Air filters; Aged; Randomized controlled trial; Cross-over studies; Public health

Introduction

Numerous studies have demonstrated that both short-term and long-term exposure to ambient particulate matter increases the incidence and mortality of respiratory and cardiovascular diseases [1-2]. The underlying mechanisms for cardiovascular disease include inflammation, altered cardiac autonomic function, shifts in the balance between coagulation and fibrinolysis, endothelial and microvascular dysfunction, and progression of atherosclerosis with plaque instability [3-4]. Elderly individuals exhibit heightened susceptibility to particulate pollution [5], and particles can infiltrate indoor environments through ventilation, posing health risks to older adults [6]. Air purifiers represent an effective measure for reducing indoor particulate concentrations [7]. Determining the purification efficacy of air purifiers in elderly residential settings and investigating the cardiopulmonary health benefits of indoor air purification is therefore critically important. Consequently, this study conducted a randomized, double-blind, crossover trial in a Chongqing nursing home to examine the cardiopulmonary function improvements associated with short-term air purifier use in healthy elderly individuals, providing a theoretical basis for establishing health building standards for older adults.

Methods

Study Subjects This study was conducted in January 2020 at a senior apartment in Jiangbei District, Chongqing, China. Twenty-six elderly volunteers were recruited through posted advertisements and face-to-face conversations. Inclusion criteria were: (1) age $\geq$ 60 years; (2) residence in the nursing home for over one year with no plans to leave during the study period. Exclusion criteria were: (1) individuals in the acute phase of cardiopulmonary disease; (2) those with smoking or alcohol consumption within one year prior to the trial. The 26

elderly participants resided in 18 rooms within the same building, with either one or two persons per room. All rooms had identical layouts consisting of a bedroom and bathroom, with no indoor sources of particulate pollution.

Study Design This randomized, double-blind, crossover intervention trial aimed to assess acute changes in health outcomes following short-term indoor air filtration. The 26 elderly participants were randomly divided into two groups (A and B) of 13 individuals each. Each participant underwent two experimental phases lasting 48 hours each, separated by a 12-day washout period. In the first phase, Group A used real air purifiers for 48 hours while Group B used sham purifiers (identical in appearance but with the high-efficiency filters removed, providing no purification function). In the second phase, the interventions were switched between groups. The air purifiers had a clean air delivery rate (CADR) of 436 m^3/h and an airflow rate of 520 m^3/h. During the 48-hour trial periods, participants were required to remain in their rooms with doors and windows closed, and meals were delivered by staff. All interventions commenced at 8:00 AM to avoid circadian variation effects. Both participants and researchers measuring health outcomes were blinded to the type of air purifier used. Written informed consent was obtained from all participants, and the study was approved by the Life Sciences Ethics Review Committee of Central China Normal University (CCNU-IRB-2019-002).

Exposure Assessment During each intervention period, environmental monitors were used to continuously measure indoor and outdoor particulate mass concentrations [including inhalable particulate matter (PM_{10}), fine particulate matter ($PM_{2\cdot5}$), and respirable particulate matter ($PM_{1\cdot0}$)] as well as temperature and humidity, with a time resolution of 1 minute. Particulate monitoring employed laser dust sensors (ZH03B), while temperature monitoring utilized polymer humidity-sensitive resistors and high-precision NTC temperature sensing elements (MHTRD06). Indoor monitoring equipment was installed at least 1 meter away from the air purifiers at a height of 0.6–1.0 meters to capture the breathing zone of elderly participants who frequently lay or sat in their rooms. The 48-hour average values served as uniform exposure levels for the one to two participants in each room. Outdoor monitoring equipment was installed in a pavilion 10 meters from the residential building within the senior apartment complex to simultaneously track outdoor particulate concentrations.

Health Indicator Testing Baseline information including age, sex, height, weight, and medical history was collected before the trial. Following each intervention, 3 ml of venous blood was collected from each participant (using EDTA tubes). Plasma was separated from blood samples and stored at -80°C. Fourteen circulating biomarkers were measured from the plasma, including eight inflammatory markers [C-reactive protein (CRP), fibrinogen, P-selectin, monocyte chemoattractant protein-1 (MCP-1), interleukin-1β (IL-1β), interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), and myeloperoxidase (MPO)]; four

coagulation markers [soluble CD40 ligand (sCD40L), plasminogen activator inhibitor-1 (PAI-1), tissue-type plasminogen activator (t-PA), and D-dimer]; and two oxidative stress markers [reactive oxygen species (ROS) and glutathione (GSH)]. All biomarkers were measured using enzyme-linked immunosorbent assay (ELISA). Fractional exhaled nitric oxide (FeNO) levels were measured using a portable NIOX MINO device. Lung function parameters including forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), and peak expiratory flow (PEF) were tested using a spirometer. Blood pressure and heart rate were measured using an upper-arm electronic blood pressure monitor. Ultimately, paired blood pressure and heart rate data were available for 24 participants, paired FeNO and lung function test results for 20 participants, and paired blood samples for 22 participants.

Statistical Analysis All analyses were performed using the "lme4" package in R software (version 4.0.4). Indoor and outdoor PM concentrations are presented as ($\bar{x}\pm s$). Linear mixed-effects models were employed to investigate the effects of indoor air purification on cardiopulmonary health indicators in the elderly. As all health indicators exhibited skewed distributions, they were log-transformed prior to statistical analysis. Log-transformed health indicators served as dependent variables, indoor purification status as the independent variable (fixed effect), and age, sex, body mass index, indoor relative humidity, and indoor temperature as fixed-effect covariates. All models included random intercepts for participants. Sensitivity analyses were conducted using linear mixed-effects models stratified by sex to explore differential effects of air purifiers on health indicators in males and females. Additionally, a sensitivity analysis was performed using indoor $PM_{2\cdot5}$ concentration as a continuous independent variable, with other variables remaining the same. All statistical tests were two-sided with α=0.05.

Results

General Characteristics Initially, 26 elderly individuals were recruited for the trial, but two withdrew during the study. The final study population comprised 12 males and 12 females with a mean age of $(82\$\pm8)years and mean body mass index of (24.7\pm3.8)kg/m\hat{}\{2\}\$$. Participants self-reported remaining indoors throughout the intervention periods and during the washout period in the nursing home. Blood pressure and heart rate measurements were completed by 24 participants; two participants refused blood draws; two were unable to complete full FeNO and lung function tests (two completed only FeNO tests and two completed only lung function tests). Consequently, paired blood pressure and heart rate data were available for 24 participants, paired FeNO and lung function test results for 20 participants, and paired blood samples for 22 participants.

Particle Exposure and Meteorological Parameters During the trial period, outdoor $PM_{1·0}$, $PM_{2·5}$, PM_{10}, temperature, and relative humidity were $(37.8\$\pm4.5)\mu g/m^{\{3\},(60.8\pm6.1)\mu g/m}\{3\}, (77.7\pm7.5)\mu g/m^{\{3\},(11.0\pm3.7)°C,and(64.6\pm5.0)\pm3.4)\mu g/m}\{3\}\$$ for $PM_{1·0}$, $(12.7\$\pm5.5)\mu g/m\hat{}\{3\}\$$ for $PM_{2·5}$, $(16.0\$\pm7.0)\mu g/m\hat{}\{3\}\$$ for PM_{10}, $(20.0\$\pm1.9)°Cfortemperature, and(52.7\pm3.8)\pm4.7)\mu g/m\hat{}\{3\}\$$ for $PM_{1·0}$, $(45.6\$\pm7.8)\mu g/m\hat{}\{3\}\$$ for $PM_{2·5}$, $(58.5\$\pm10.1)\mu g/m\hat{}\{3\}\$$ for PM_{10}, $(19.8\$\pm1.5)°Cfortemperature, and(51.4\pm\$4.6)\%$ for relative humidity.

Health Indicator Results The results for eight systemic inflammatory markers, four coagulation factors, blood pressure, heart rate, lung function, airway inflammation, and two oxidative stress biomarkers in elderly participants after 48 hours of real and sham purification are presented in Table 1 .

Linear Mixed-Effects Model Results Mixed-effects model results revealed that compared with sham purifiers, real air purification significantly improved three blood inflammatory markers, two coagulation factors, and heart rate (P<0.05), as shown in Table 2 . Specifically, compared with elderly individuals exposed to sham purifiers, those exposed to real purifiers exhibited changes of -15.1% [95%CI (-23.1%, -6.3%)], -17.7% [95%CI (-22.9%, -12.3%)], and -17.2% [95%CI (-23.9%, -9.8%)] in blood inflammatory factors fibrinogen, MCP-1, and MPO, respectively. Coagulation factors PAI-1 and t-PA changed by -14.9% [95%CI (-21.1%, -8.2%)] and -13.5% [95%CI (-18.7%, -8.0%)], respectively. Heart rate changed by -5.9% [95%CI (-10.1%, -1.4%)]. The order of real versus sham purifier exposure had no effect on any health indicator (P>0.05).

Effects by Gender Stratified by sex, sensitivity analyses using mixed-effects models revealed that compared with sham purifiers, real air purifiers reduced CRP, fibrinogen, MCP-1, IL-1β, MPO, PAI-1, and t-PA in male elderly participants (P<0.05). In female elderly participants, real air purifiers reduced fibrinogen, MCP-1, PAI-1, t-PA, and heart rate compared with sham purifiers (P<0.05), as shown in Table 3 .

Dose-Response Relationship Linear mixed-effects model results indicated that for every 1 g/m^3 increase in indoor $PM_{2·5}$ concentration, fibrinogen, MCP-1, MPO, PAI-1, t-PA, D-dimer, and heart rate in the elderly increased by 0.51%, 0.48%, 0.56%, 0.49%, 0.43%, 0.31%, and 0.20%, respectively (P<0.05), as presented in Table 4 .

Discussion

Under sham purifier conditions, indoor $PM_{2·5}$ concentration in the senior apartment was 45.6 g/m^3, exceeding the World Health Organization guideline value of 25 g/m^3 [8]. Following air purifier use, indoor $PM_{2·5}$ concentration decreased to 12.7 g/m^3, meeting WHO standards. Air purifiers can effectively

reduce indoor particulate concentrations, thereby mitigating harm from inhalable particle exposure in the elderly. Short-term indoor air purification may confer cardiopulmonary benefits.

This study found that following air purification and reduced particle levels, three inflammatory markers (fibrinogen, MCP-1, MPO), two coagulation markers (PAI-1 and t-PA), and heart rate all decreased correspondingly. The relationship between air pollution and cardiovascular disease involves multiple pathophysiological pathways, including systemic inflammation and coagulation [9]. CRP is a reliable and independent predictor of cardiovascular events [10]. Several cross-sectional studies have found positive associations between particulate matter exposure and CRP [11-12]. In response to vascular injury or inflammation, the human body increases coagulation factors to enhance and complete thrombus formation, with fibrinogen playing a key role in this process [13-14]. A study of 44 healthy adults in Tehran, Iran found significant differences in fibrinogen levels under varying air pollution conditions, with the highest levels observed during dust storms [15]. Another study of 40 healthy young adults also found a clear correlation between ambient $PM_{2·5}$ concentration and fibrinogen levels [16]. Our findings are consistent with these results, though our experimental conditions differed: this study was conducted under normal atmospheric conditions where PM primarily originated from outdoor traffic emissions rather than extreme weather events such as dust storms. A randomized, double-blind intervention study of air purifiers conducted under daily atmospheric conditions in Beijing, China found that air purification reduced CRP and fibrinogen in young adults, though not significantly [17]. In contrast, our study demonstrated significant changes in fibrinogen following 48 hours of indoor air purification in the elderly, likely due to age-related physiological decline that increases vulnerability to particulate-induced cardiovascular damage. Thus, the potential health benefits of air purification may be greater for older adults than for the general population.

The biological mechanisms linking inhalable particulate matter exposure to venous thromboembolism remain incompletely understood, though research suggests one possible mechanism involves hypercoagulability and enhanced thrombosis formation [18]. Our finding of significantly reduced PAI-1 and t-PA following air purification supports this hypothesis.

This study examined multiple health indicators, providing exploratory value for research on indoor particulate matter in the elderly. However, the study included only 24 participants across 16 rooms, representing a relatively small sample size that may have limited detection of potentially important but modest differences.

In summary, this study found that air purifier use significantly reduced fibrinogen, MCP-1, MPO, PAI-1, t-PA, and heart rate in the elderly. As $PM_{2·5}$ concentration increased, fibrinogen, MCP-1, MPO, PAI-1, t-PA, D-dimer, and heart rate increased correspondingly. Air purification may improve circulatory and cardiopulmonary health in the elderly.

Author Contributions

ZHOU Min: Investigation, methodology, resources, validation, writing—original draft. ZHENG Ziguang: Investigation, project administration. YOU Hongyu: Formal analysis, software. GUO Miao: Data curation, visualization. YU Wei: Conceptualization, funding acquisition, project administration, resources, supervision, writing—review & editing.

Conflict of Interest

The authors declare no conflict of interest.

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Note: Figure translations are in progress. See original paper for figures.